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Effective weed management strategy for maize (*Zea mays*) under rainfed condition of southern Rajasthan

HARGILAS*

Maharana Pratap University of Agriculture and Technology, Rajasthan 327 001, India

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ABSTRACT

A field experiment was conducted during the rainy season of 2015 and 2016 at Agricultural Research Station (MPUAT), Banswara, Rajasthan to find out effective weed management strategy for enhancing productivity and economic return of maize (*Zea mays* L.) under rain-fed condition of southern Rajasthan. Ten treatment combinations of pre-emergence (atrazine and pendimethalin), post-emergence (2,4-D amine, halosulfuron and tembotrione) herbicides with weed free and weedy check were laid out in randomized block design with three replications. The result revealed that application of atrazine 50WP @1.5 kg/ha PE fb tembotrione 42SC @286 g/ha POE at 25 DAS significantly reduced weed density and weed dry weight with increased weed control efficiency and weed control index at 50 DAS as compared to other herbicidal treatments. The weed free treatment gave significantly higher plant height, yield attributes, grain yield (6.31 and 6.86 t/ha) and stover yield (6.87 and 8.15 t/ha), HEI (67.51%) and gross return (₹ 88363/ha) followed by application of atrazine as PE fb tembotrione as POE at 25 DAS over rest of the treatments. While, net return (₹ 55498/ha) and B:C ratio (2.05) recorded highest with application of atrazine PE fb tembotrione POE at 25 DAS than weed free and rest of the treatments. Hence, sequential application of atrazine 50WP @1.5 kg/ha PE fb tembotrione 42SC @286 g/ha POE at 25 DAS may be recommended for enhancing productivity and economic return through effective weed management in maize under rainfed condition of southern Rajasthan.

Key words: B:C ratio, Maize, Tembotrione, Weed control efficiency, Yield

Maize (*Zea mays* L.) is the most versatile crop with wider adaptability to grow in varied agro-ecological regions from semi-arid to sub-tropical conditions under diverse growing seasons. India has ranked 4th in maize area (8.71 m ha) with production of 22.26 Mt. (GoI 2015). Maize grain is mainly used for feed (59%), food (10%) and industrial (17%), export (10%) and other purpose (4%) in the country (Yadav *et al*. 2016). Responding to its multiple uses, the demand for maize is constantly increasing in the global market. Growing market demand by the feed and starch industry and increase in minimum support price from ₹ 540/q in the year of 2006-07 to ₹ 1325/q in the year of 2015-16 led to make maize as a more competitive crop and encouraged farmers to grow maize to a large extent (Anonymous 2016). However, maize productivity has not increased proportionately, significant yield gaps are evident across the maize growing areas in the country. Maize crop is mainly cultivated across the country during the rainy season, it's productivity gets affected by abiotic and biotic factors. Excluding abiotic factors, yield loss in maize is mainly due to crop-weed competition. Weeds compete with the crop plants for resources such as light, nutrients; space and moisture that influence the morphology and phonology of the crop, coupled with congenial weather conditions that allow luxuriant weed growth, which may reduce yield by 38-100% (Dass *et al.* 2012). The critical period of crop-weed competition in maize was 15-45 days after sowing reported during rainy season maize (Kumar *et al*. 2015). Weeds are not only competing with crop for water, nutrient, light and space but also provide harbor for insect-pests. The mechanical weeding is partially ineffective because weeds also grow in intra row space and manual weeding is also impossible due to incessant rains during critical period of crop-weed competition makes the situation worse. Hence, the present study was undertaken to evaluate the bio-efficacy of new herbicides in maize under rain-fed condition of southern Rajasthan.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive rainy seasons (July-October) of 2015 and 2016 at Agricultural Research Station (MPUAT), Banswara (Rajasthan) located at 23° 33' N latitude, 74° 27' E longitude, and altitude of 220 m amsl. The experimental site was characterized by erratic and uneven rainfall pattern that peaks from June to october. The soil of experimental field was clay loam in texture, slightly alkaline in reaction and low in organic carbon (0.43%), available N (234 kg/ha),

*Corresponding author e-mail: hargilasm73@gmail.com

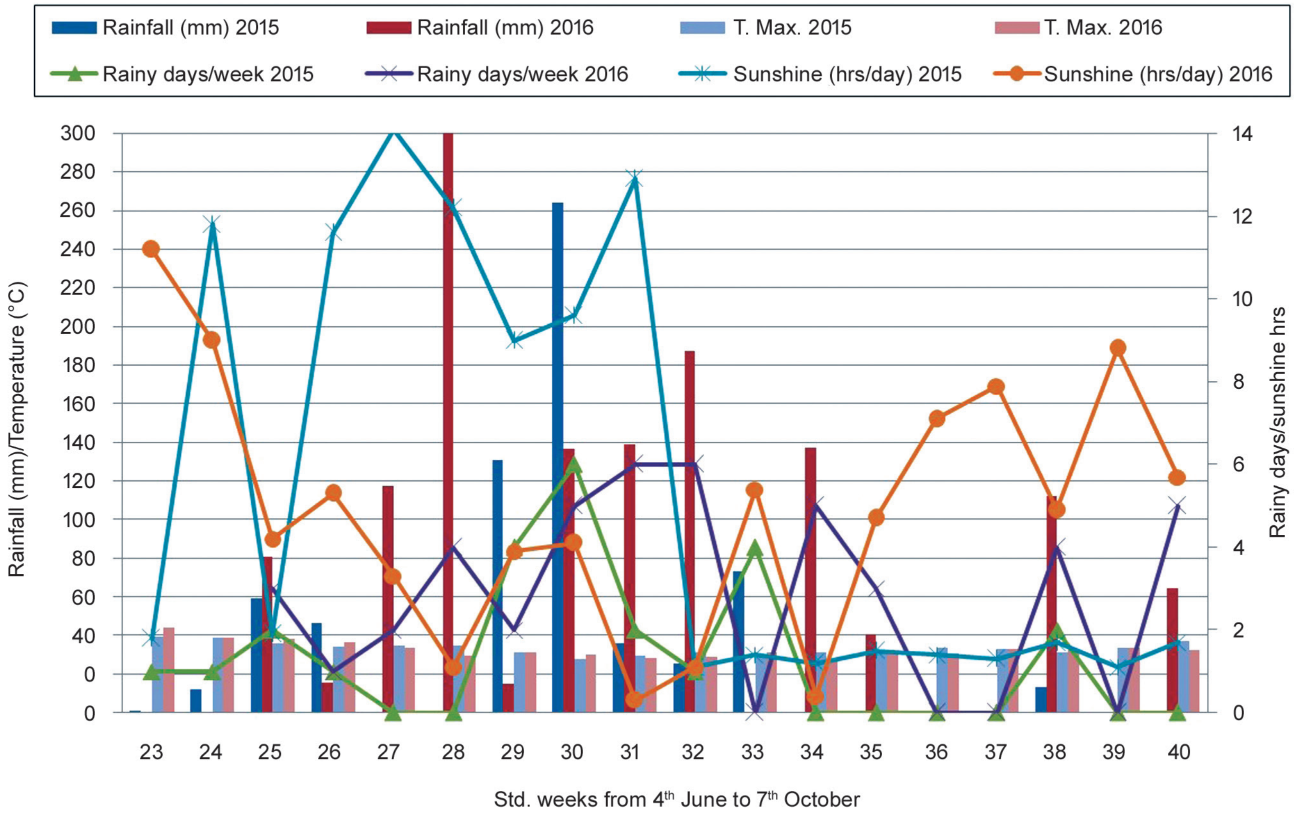

Fig 1 Weekly meteorological observatory data during experimental years (2015 & 2016)

available P_2O_5 (18 kg/ha) and high in available K_2O (385 kg/ha). The total rainfall received was 663 and 1381 mm during June to October of 2015 and 2016, respectively (Fig 1). The treatments comprised weedy check (T_1), weed free (T_2), atrazine 50WP @1.5 kg/ha PE (T_3), atrazine 50WP@0.75 kg/ha+pendimethalin 30EC@1.50 l/ha PE (T_4), atrazine 50WP@0.75 kg/ha + 2, 4-D amine 58SL@690 ml/ha POE at 25 DAS (T_5), halosulfuron 75WG@90 g/ha POE at 25 DAS (T_6), atrazine 50WP@1.5 kg/ha PE fb halosulfuron 75WG@90 g./ha POE at 25 DAS (T_7), tembotrione 42SC@286 g/ha POE at 25 DAS (T_8), pendimethalin 30EC@ 3.0 l/ha PE fb atrazine 50WP@0.75 kg/ha+2,4-D amine 58SL@690 ml/ha POE at 25 DAS (T_9) and atrazine 50WP@1.5 kg/ha PE fb tembotrione 42SC@286 g/ha POE at 25 DAS (T_{10}) were laid out in randomized block design with three replications. The seed of maize hybrid Bio 9681 was dibbled manually at spacing of 60×25cm using 20 kg seed/ha in the first week of July during both the years. The recommended dose of fertilizers for maize was 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. Calibration quantity of herbicides was applied as an aqueous spray (500 l/ha) with a manual operated Knapsack sprayer fitted with flat-fan nozzle. Pre-emergence (PE) application of herbicides was done within 24 h of sowing and post emergence (POE) herbicides were applied after 25 DAS during rain free condition. All other practices were followed as per recommendation. Data pertaining to weed density and weed dry matter weight were recorded 50 days after sowing maize crop from two places in each plot using 100 cm × 100 cm quadrate and counted species-wise. The efficiency of weed management treatment was assessed by weed control efficiency (WCE) and control index (WCI) that calculated as:

$$\text{WCE (\%)} = \frac{WD_c - WD_t}{WD_c} \times 100$$

where WDc is the weed density (No. of weeds/ m^2) in control plot and WDt is weed density (No. of weeds (g/m^2) in the respective treatment.

$$\text{WCI (\%)} = \frac{WDM_c - WDM_t}{WDM_c} \times 100$$

where WDMc is weeds dry matter (g/m^2) in control plot and WDMt is weed dry matter (g/m^2) in the respective treatment.

Herbicide efficiency index (HEI) was computed using the formula (Krishnamurthy *et al.*1975):

$$\text{HEI (\%)} = \frac{\text{Yield in treated plot} - \text{Yield in control plot}}{\text{Yield in treated plot}} \times 100$$

Statistical analysis for data recorded on weeds and maize was done following the analysis of variance technique for randomized block design (RBD) as per Gomez and Gomez (1976). Statistical significance was tested by applying F-test at 0.05 level of probability and critical differences were calculated for those parameters which were found significant ($P \leq 0.05$) to compare the effects of different treatments. Based on the prevailing market price of produce and cost of cultivation, gross returns and net returns were computed.

RESULTS AND DISCUSSION

Weed density and dry matter production: The weedy treatment of experimental field was infested with 55% grassy weeds, followed by 34% broad-leaf weeds and 11% sedges. The predominant grassy weeds species were *Echinochloa colonum*, *Echinochloa crus-galli, Eleusine indica, Digitaria sanguinalis*, *Dinebra retroxa* and *Cynodon dactylon,* while broad-leaf weeds (BLW) species were *Trianthema portulacastrum, Digera arvensis, Commelina benghalensis*, *Amaranthus* spp., *Phylanthus niruri, Celosia viscose, Euphorbia genicullata, Euphorbia hirta, Abutilon indicum, Eclipta alba, Achalypha indica* and *Parthenium hysterophorus* and sedges weeds species were *Cyperus rotendus* and *Cyperus difformis.* In the pooled data of both the years (2015 and 2016), the highest weed density of grassy weeds (205.7/m^2), BLW (127.7/m^2) and sedges (40.1/m^2) was recorded in weedy check at 50 DAS (Table 1). All the weed control treatments significantly reduced the density and dry matter weight as compared to weedy check. Herbicides used in the experimental field were broad spectrum in nature. But, weed density and weed dry matter reduced through PE herbicides of T_3 and T_4 than POE herbicides. Among, the POE herbicides, the sole application of tembotrione 42SC@286 ml/ha (T_8) was found the best in controlling grassy weeds (64.4/m^2) as well as broad leaf weeds (37.8/m^2) followed by T_5, whereas, T_6 was most effective in controlling the sedges (8.0/m^2) at 50 DAS. Treatment (T_8) was recorded to be the most effective combination to reduce the density of all weeds compared to rest of treatments. All weed-control treatments significantly reduced dry matter weight of all weed flora compared to weedy check treatment at 50 DAS (Table 1). The maximum dry matter weight of grassy weeds (133.7g/m^2), broad leaf weeds (102.1 g/m^2) and sedges (36.1g/m^2) recorded in weedy check, which were significantly reduced with application of pre and post-emergence herbicides and minimum weed dry matter accumulation was recorded in T_{10}. The reduction of weed dry weight in treatment applied plots as compared to untreated plot. The similar results were reported by Singh *et al.* (2012) and Hargilas (2017).

Weed control efficiency and weed control index: The value of weed control efficiency and weed control index indicates efficacy of weed management practices (Table 1). The highest and lowest weed control efficiency (WCE) and weed control index (WCI) of grasses, broad leaf weed and sedges was recorded in weed free and weedy check treatments, respectively. Grasses (41.1%), broad leaf (38.7%), and sedges (6.4%) were controlled in T_3. Weed control efficiency of T_3 was higher in case of grasses and broad leaf weed, but lower in case of sedges compared to T_4. Tembotrione (T_8) was significantly effective in control of grasses (68.6%) and broad leaf (67.5%) than halosulfuron (T_6), whereas, halosulfuron was more effective for controlling sedges (80%) compared to other post-emergence herbicides. Overall, the highest weed control efficiency (68%) was recorded with tembotrione compared to other post emergence herbicide alone. The sequential application of atrazine PE followed by tembotrione (T_{10}) recorded higher control of sedges (84.0%) and broad leaf (92.3%) than rest herbicides. Overall, higher weed control efficiency (87%) was recorded in T_{10} compared to herbicides use as pre-emergence and post-emergence alone and combined and pre-emergence followed by post-emergence, respectively. The better performance of T_{10} may be attributed to the fact that pre-emergence application of atrazine effectively controlled grassy, broad leaf and sedges through photosynthetic inhibition of weed flora and weeds were further taken care by post-emergence application of tembotrione through inhibiting pigment sysnthesis of weeds in standing crop. The result was confirmed by Hargilas (2017).

The weed control index (WCI) varied with dry matter weight of weeds in respective treatment (Table 1). Among the herbicides, the highest weed control index of grasses (80.4%), broad leaf (91.6%) and sedges (94.3%) was recorded in T_{10}. The weed control index was higher in T_8 to T_6 and 2, 4-D amine because tembotrione was effective control for all types of weeds than rest of herbicides. The trend of the weed control index of all weeds was similar to weed control efficiency in respective treatment. This might be due to effective control of weeds for long periods, resulting in low weed dry matter weight. Similar results have been reported by Bollman (2008).

Growth and yield attributes: The weed free treatment obtained highest plant height (228 and 234 cm) followed by atrazine 50WP@1.5 kg/ha PE fb tembotrione 42SL@286 g/ha POE at 25 DAS (225 and 231 cm) and significantly superior than rest of the treatments during both the years (Table 2). The minimum plant height was recorded in weedy check. The vigorous plant growth in T_2 and T_{10} treatments might be due to lesser crop-weed completion for growth resources like nutrient, soil moisture, sunlight etc.

Plant population was 59650 and 62880 plants/ha at harvest counted under weed free plot (T_2) followed by $T_{10,}$ $T_{8,}$ T_9 and T_5 during the year 2015 and 2016 (Table 2). Whereas, lower plant population was recorded under weedy check (38400 and 24430 plants/ha). This could be due to use of atrazine that provided weed free condition for crop growth upto 15 DAS through inhibiting the initial growth of weed flora, and then application of tembotrione at 25 DAS to kill weed flora in standing crop. Thereby, crop plants did better utilization of available resources of ground and above ground. These observations were in agreement with Prasad *et al*. (2008).

Hand weeding thrice at 20, 40 and 60 DAS in weed free treatment, proved its superiority by producing significantly higher values of yield attributes as number of cobs, grains/cob and test weight compared to herbicidal and weedy check treatments (Table 2). The maximum cobs (59380

Table 1 Effect of weed management on weed density, weed dry matter, weed control efficiency and weed control index (Pooled data of 2 years)

Treatment	Weed density (no/m^2)				Weed dry matter (g/m^2)				Weed control efficiency (%)				Weed control index (%)			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
T_1: Weedy check	205.71	127.67	40.11	373.49	133.71	102.14	36.10	271.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_2: Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	100	100	100	100	100	100	100.
T_3: Atrazine 50WP@1.5 kg/ha PE	121.88	74.83	37.55	234.26	85.32	63.61	30.04	178.97	41.11	38.68	6.41	36.93	36.44	34.26	16.45	34.13
T_4 : Atrazine 50WP@0.75 kg/ha + pendimethalin 30EC@ 01.5l/ha PE	125.56	80.75	32.45	238.76	87.89	68.64	25.96	182.49	36.85	34.25	19.04	34.18	33.83	29.39	27.75	31.34
T_5: Atrazine 50W P @ 0.75 kg/ha + 2,4-D amin e 58SL@690 ml/ha POE at 25 DAS	108.75	35.93	32.00	176.68	89.18	18.68	25.60	133.46	45.20	70.60	19.94	51.14	32.73	80.69	28.84	49.70
T_6: Halosulfuron 75WG@90 g/ha POE at 25 DAS	106.37	59.17	8.00	173.54	79.78	38.46	4.80	123.05	48.66	51.47	80.01	53.25	41.04	60.16	86.62	54.57
T_7: Atrazine 50WP@1.5 kg/ha PE fb halosulfuron 75WG@ 90 g/ha PoE at 25 DAS	104.56	44.30	2.67	151.52	62.74	26.58	1.34	90.66	50.03	63.46	93.35	59.60	53.73	72.36	96.27	66.98
T_8: Tembotrione 42SC@286 ml/ha PoE at 25 DAS	64.38	37.75	16.00	118.13	41.85	28.31	14.40	84.55	68.62	67.52	60.07	67.70	68.85	69.33	60.06	68.50
T_9 : Pendimethalin 30EC@ 3.0 l/ha PE fb atrazine 50WP@ 0.75 kg/ha +2,4-D amine 58SL@ 690ml / a.i./ha POE at 25 DAS	98.97	18.33	37.47	154.77	49.49	9.17	31.85	90.50	51.79	84.57	6.39	57.99	63.26	90.16	11.67	66.52
T_{10} : Atrazine 50WP@1.0 kg a.i./ha PE fb tembotrione 42SC@286 ml /ha POE at 25 DAS	32.74	9.33	5.33	47.40	26.19	7.46	2.05	35.69	83.98	92.27	86.46	87.17	80.37	91.63	94.27	86.61
LSD (P=0.05)	6.44	7.26	9.56	55.04	7.16	3.38	1.34	49.95	20.24	13.63	5.59	12.94	21.65	13.71	9.21	12.91

Table 2 Effect of weed management on growth and yield attributes and grain and stover yield of maize (2015 and 2016)

Treatment	Plant height (cm)		No of plants (000/ha)		No of cobs (000/ha)		No of grains/cob		Test weight (g)		Grain yield (t/ha)		Stover yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T_1: Weedy check	170	162	38.40	29.32	32.18	24.43	326	318	259	251	2.38	1.72	4.75	2.99
T_2: Weed free	228	234	59.65	62.88	59.38	67.61	652	656	320	328	5.76	6.86	6.87	8.15
T_3: Atra$_2$ zine 50WP@1.5 kg/ha PE	207	213	45.12	46.04	38.58	48.53	465	485	280	286	3.23	3.79	5.03	5.50
T_4 : Atrazine 50WP@0.75 kg/ha + pendimethalin 30EC@ 01.5l/ha PE	215	217	45.00	47.73	41.30	46.61	479	503	285	287	3.31	3.83	5.11	5.51
T_5: Atrazine 50W P @ 0.75 kg/ha + 2,4-D amin e 58SL@690 ml/ha POE at 25 DAS	198	204	56.07	57.55	49.93	60.48	509	515	293	293	3.57	4.27	5.37	6.26
T_6: Halosulfuron 75WG@90 g /ha POE at 25 DAS	172	180	35.66	41.72	27.63	35.02	404	408	261	265	2.24	2.80	3.79	3.99
T_7: Atrazine 50WP@1.5 kg/ha PE fb halosulfuron 75WG@ 90 g/ha PoE at 25 DAS	163	203	45.56	50.31	38.59	38.78	493	499	263	267	3.42	3.65	4.82	5.23
T_8: Tembotrione 42SC@286 ml/ha PoE at 25 DAS	213	219	57.19	58.43	50.39	61.04	527	539	309	311	4.32	5.16	5.94	6.48
T_9 : Pendimethalin 30EC@ 3.0 l/ha PE fb atrazine 50WP@ 0.75 kg/ha + 2,4-D amine 58SL@ 690ml/a.i./ha POE at 25 DAS	210	218	55.60	59.80	48.92	58.09	516	530	293	295	3.83	4.60	5.88	6.36
T_{10} : Atrazine 50WP@1.0 kg a.i./ha PE fb tembotrione 42SC@286 ml /ha POE at 25 DAS	225	231	59.54	61.26	55.94	65.86	631	649	317	317	5.55	6.25	6.26	7.81
LSD (P=0.5)	12.09	15.47	9.68	9.59	10.9	8.06	66.6	32.9	8.2	8.43	0.54	0.87	0.67	1.24

and 67610/ha) was recorded under weed free treatment, which was at par with T_{10} and significantly superior over other treatments. The maximum grains (652 and 649/cob) were recorded in weed free treatment followed by T_{10} and significantly superior over other treatments. Herbicidal treatments were observed to initiate more grains per cob, resulting in up to 24 to 104% increase as compared to weedy check (326 and 318 grains/cob). Among the herbicidal treatments, halosulfuron POE at 25 DAS produced lower grains (404 and 408/cob) compared to other herbicidal treatments. Similarly, the test weight result was obtained. The maximum test weight (320 and 328 g) was recorded in weed free treatment followed by T_{10} and significantly higher than rest treatments. Among herbicidal treatment, halosulfuron POE gave lower test weight (261 and 265 g) and minimum test weight (259 and 251 g) was obtained in weedy check. These data directly affected association of crop-weed completion. The most weed affected treatment obtained a lower number of cobs and test weight, it might be due to lesser photosynthate accumulation through lesser nutrient and water uptake and lesser sunlight received under higher crop-weed competition treatment. Whereas, lesser crop-weed competitive treatments produced higher cobs and test weight to get a higher accumulation of photosynthates. Similar findings have been reported by Swetha *et al.* (2015).

Yield: Weed free treatment produced maximum grain yield (5.76 and 6.86 t/ha) and stover yield (6.87 and 8.15 t/ha) which were 20% and 131% higher over weedy check during 2015 and 2016 (Table 2). This could be attributed to least competition offered by weeds for nutrients and moisture during crop span, which ultimately improved all yield attributes besides increased rate of nutrient uptake, cumulatively helped the crop plants to produce more area for high photosynthetic rate as well as higher translocation of photosynthates from sources-sink. The sequential application of atrazine 50WP@1.5 kg/ha PE fb tembotrione 42SC@286 g/ha POE at 25 DAS also improved the yield and was the next best treatment. Among, the herbicidal treatments, the superiority of pre-emergence application of atrazine+pendimethalin gave 2.48 and 1.06% higher grain yield over atrazine alone; might be owing to the effective and broad-spectrum weed-controlling ability of atrazine and thereby, reducing the crop-weed competition. However, application of T_8 produced higher grain yield (4.32 and 5.16 t/ha) followed by T_5 (3.57 and 4.27 t/ha) and significantly superior over rest of the herbicidal treatments. Between herbicidal treatments, halosulfuron 75WG@90 g/ha POE at 25 DAS produced lowest grain yield (2.24 and 2.80 t/ha), because it exhibited phytotoxicity symptoms in crop plants till 10 days after spraying, resulting crop was suppressed during the active growth stage. The sequential application of atrazine PE fb tembotrione 42SL@286 g/ha POE at 25 DAS (T_{10}) recorded significantly superior over other herbicidal treatments. This might be due to better translocation of photosynthates from source-sink. The synergistic effect of growth parameters and yield attributes was significantly reflected in grain and stover yield. The findings are similar to Singh *et al.* (2010) and Hargilas (2017).

Herbicidal efficiency index: The pooled data of herbicidal efficiency index revealed that the maximum herbicidal efficiency index (67.51%) was recorded under weed free treatment, whereas, minimum HEI was recorded in weedy check. Among the herbicidal treatment, T_{10} recorded higher HEI (65.27%) followed by T_8 (56.77%) and significantly superior over rest of the herbicidal treatments. These results directly correlated to efficacy of treatments with grain yield of crop. Weed free treatment followed by sequential application of atrazine 50 WP@1.5 kg/ha as PE fb tembotrione 42SC@286 g/ha as POE found better treatments. This could be due to better weed control without phytotoxic effect on crop.

Economics: With respect to economics, the maximum gross return (₹ 88363/ha) was obtained with weed free treatment which was at par with the sequential application of atrazine 50WP@1.5 kg/ha PE fb tembotrione 42SL@286 g/ha POE at 25 DAS (₹ 82588/ha) and significantly superior over rest of the treatments, while minimum gross return (₹ 28659/ha) was recorded with weedy check. Whereas, maximum net return (₹ 55498/ ha) was recorded in T_{10} which was recorded significantly superior to other treatments and minimum net return (₹ 7969/ha) was found with T_1. Similarly, net return per rupee spent (B : C ratio) was recorded highest (2.05) in T_{10} at 25 DAS which was significantly superior over rest of the treatments. This may be due to higher grain yield obtained over other treatment except weed free and lower cost of cultivation compared to most of herbicidal treatments and weed free check. The minimum B : C ratio (0.39) was recorded in T_2 due to lowest grain yield. In spite of higher grain yield in weed free treatment, B : C (0.66) might be due to keeping the field free from weeds throughout the crop span by manual weeding, which includes the huge cost of labour compared to other weed management treatments. Similar findings were reported by Rana *et al.* (2017) and Hargilas (2017).

Based on the results of this study, it can be concluded that higher productivity and economic return of maize can be obtained through effective weed management with pre-emergence application of atrazine 50 WP@1.5 kg /ha fb tembotrione 42SC@286 ml/ha at 25 DAS under rainfed condition of southern Rajasthan.

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